~~What Is Claimed Is:~~ CLAIMS

1. A method for contact imaging of dielectric permittivity using a near-field scanning microwave microscope having a resonator with a probe tip comprising the steps of:
   (a) calibrating the near-field scanning microwave microscope to determine a geometry descriptor of the probe tip;
   (b) generating calibration curves;
   (c) scanning a test sample in contact with the probe tip at scanning locations and generating at least one test sample frequency shift value at each scanning location; and
   (d) determining the dielectric permittivity of the test sample at the sample locations based on the respective generated test sample frequency shift values and the generated calibration curves.

2. The method of claim 1, wherein said calibrating step (a) includes the steps of:
   (i) selecting a resonant frequency of the near-field scanning microwave microscope;
   (ii) scanning each of said at least two calibration samples, where for each scan the probe tip is first brought into contact with each of said at least two calibration samples;
   (iii) moving the microscope probe to a predetermined background measurement position;
   (iv) measuring a background resonant frequency at said predetermined background measurement position;

(v) moving the probe tip into contact with said one of said at least two calibration samples at a scanning position;

(vi) measuring a contact resonant frequency at said scanning position;

(vii) calculating the difference between said contact resonant frequency and said background resonant frequency;

(viii) storing in memory said calculated difference as a calibration sample resonant frequency shift value;

(ix) moving the sample to the next scanning position;

(x) determining if said next scanning position is the end of a scan line;

(xi) repeating steps (vi) through (x) until said end of a scan line has been reached;

(xii) moving the sample to the next scan line;

(xiii) determining if said next scan line is the end of a scan area;

(xiv) repeating steps (iii) through (xiii) for each of said at least two calibration samples until said end of a scan area has been reached.

3. The method of claim 2, wherein the resonator includes a microscope transmission line, and wherein said step (iii) comprises moving the microscope probe to a height 1.5 times greater than the diameter of the microscope transmission line.

4. The method of claim 2, wherein said step (iii) comprises moving the microscope probe to a height where the calibration sample no longer perturbs the resonator.

5. The method of claim 2, wherein said step (iii) comprises moving the microscope probe to a height at least approximately 3 millimeters above the calibration sample.

6. The method of claim 1, wherein the geometry descriptor comprises an aspect ratio of the probe tip, and the calibration step (a) further includes calculating the aspect ratio of the microscope probe tip as $\Delta z/\Delta r$, where Δz is a distance along a z-direction parallel to a length of the resonator and the probe tip and Δr is a radius distance extending from the central axis of the probe tip to its outermost surface.

7. The method of claim 1, wherein the scanning step (c) includes the steps of:

(i) selecting a resonant frequency of the near-field scanning microwave microscope;

(ii) placing said test sample on the microscope stage;

(iii) moving the probe tip into contact with said test sample;

(iv) storing a position value corresponding to the point of contact with said test sample;

(v) moving the probe to a predetermined background measurement position;

(vi) measuring a background resonant frequency at said background measurement position;

(vii) moving the probe tip into contact with said test sample at the scanning position;

(viii) measuring the contact resonant frequency at said scanning position;

(ix) calculating the difference between said contact resonant frequency and said background resonant frequency;

(x) storing in memory said calculated difference as a test sample resonant frequency shift value;

(xi) moving the sample to the next scanning position;

(xii) determining if said next scanning position is the end of a scan line;

(xiii) repeating steps (viii) through (xii) until said end of a scan line has been reached;

(xiv) moving the sample to the next scan line;

(xv) determining if said next scan line is the end of a scan area;

(xvi) repeating steps (v) through (xv) until said end of a scan area has been reached.

8. The method of claim 7, wherein the resonator includes a microscope transmission line, and wherein said step (v) comprises moving the microscope probe to a height that is at least approximately 1.5 times greater than the diameter of the microscope transmission line.

9. The method of claim 7, wherein said step (v) comprises moving the probe to a height where the test sample no longer perturbs the resonator.

10. The method of claim 7, wherein said step (v) comprises moving the probe to a height at least approximately 3 millimeters above the test sample.

11. The method of claim 1, wherein the scanning step (c) includes placing a bulk test sample on the microscope stage.

12. The method of claim 11, wherein the generating a calibration curve step (b) includes the steps of:

  (i) storing electric field configuration data files, wherein the data corresponds to a model sample having approximately the same first thickness and further having approximately the same permittivity as one of said at least two calibration samples with known dielectric properties; and wherein the data stored is representative of electric field values at respective ε_r and α over a predetermined range of ε_r and α, where ε_r is a dielectric permittivity value and α is the probe tip geometry descriptor;

  (ii) generating a first model calibration curve using said stored electric field configuration data;

  (iii) generating a second model calibration curve using said stored electric field configuration data;

  (iv) generating a probe calibration curve using said first and second generated model calibration curves and said generated calibration sample frequency shift values; and

(v) determining the geometry descriptor of the probe tip at the time of scanning of the test sample based upon the positioning of said generated probe calibration curve in relation to said first and second generated model calibration curves.

13. The method of claim 12 wherein the generating a first model calibration curve using said previously stored electric field configuration data (ii) includes the steps of:

(1) reading from a first electric field configuration data file where α= a first probe tip geometry descriptor value, a first previously stored electric field value (E_1) and a first permittivity value (ε_{r1});

(2) reading from a second electric field configuration data file where α= a first probe tip geometry descriptor value, a second previously stored electrical field value (E_2);

(3) calculating a point on the first model calibration curve by solving the equation

$$\frac{\Delta f}{f} \approx \frac{\epsilon_0}{4W}\int_{Vs}\left(\epsilon_{r2} - \epsilon_{r1}\right)\vec{E}_1 \bullet \vec{E}_2\, dV \text{ ; and}$$

(4) repeating steps (1) through (3) until a predetermined number of points on the first model calibration curve have been generated.

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14. The method of claim 12 wherein the generating a second model calibration curve using said previously stored electric field configuration data files step (iii) includes the steps of:

(1) reading from a first previously stored electric field configuration data file where α=a second probe tip geometry descriptor value, a first previously stored electric field value (E_1) and a first permittivity value (ε_{r1});

(2) reading from a second previously stored electric field configuration data file where α= a second probe tip geometry descriptor value, a second previously stored electric field value (E_2) and a second permittivity value (ε_{r2});

(3) calculating a point on the second model calibration curve by solving the equation

$$\frac{\Delta f}{f} \approx \frac{\epsilon_0}{4W} \int_{Vs} \left(\epsilon_{r2} - \epsilon_{r1}\right) \vec{E}_1 \bullet \vec{E}_2 \, dV \text{; and}$$

(4) repeating steps (1) through (3) until a predetermined number of points on the second model calibration curve have been generated.

15. The method of claim 1, wherein the scanning step (c) includes arranging a thin film test sample on top of a dielectric substrate having approximately the same first determined thickness and the same permittivity as at least one of said calibration samples and then placing said arrangement on the microscope stage.

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16. The method of claim 15, wherein the generating a calibration curve includes the steps of:

(i) storing electric field configuration data files wherein the data corresponds to a model sample having a thin film of approximately the same second determined thickness and a known dielectric permittivity value arranged on top of said dielectric substrate having approximately the same first determined thickness and the same permittivity as at least one of said calibration samples with known dielectric properties; wherein the stored data files are representative of electric field values at respective ε_r and α over a predetermined range of ε_r and α, wherein ε_r is a dielectric permittivity value for the model sample thin film and α is representative of a probe tip geometry descriptor;

(ii) generating a first test sample calibration curve using said stored electric field configuration data files;

(iii) generating a second test sample calibration curve using said stored electric field configuration data files;

(iv) generating an additional test sample calibration curve using said first and second test sample calibration curves and said generated test sample frequency shift values;

17. The method of claim 16 wherein the generating a first test sample calibration curve using said previously stored electric field configuration data files step (ii) includes the steps of:

(1) reading from a first electric field configuration data file where α= a first probe tip geometry descriptor value, a first previously stored electric field value (E_1) and a first permittivity value (ε_{r1}) where ε_{r1} is the permittivity of said thin film having approximately the same second determined thickness and known dielectric permittivity;

(2) reading from a second electric field configuration

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data file where α= a first probe tip geometry descriptor value, a second previously stored electric field value (E_2) and a second permittivity value (ε_{r2}) where ε_{r2} is the permittivity of said thin film having approximately the same second determined thickness and known dielectric permittivity;

(3) calculating a point on the first test sample calibration curve by solving the equation

$$\frac{\Delta f}{f} \approx \frac{\epsilon_0}{4W}\int_{Vs}\left(\epsilon_{r2} - \epsilon_{r1}\right)\vec{E}_1 \bullet \vec{E}_2\, dV \text{ ; and}$$

(4) repeating steps (1) through (3) until a predetermined number of points on the first test sample calibration curve have been generated.

18. The method of claim 16 wherein the generating a second test sample calibration curve using said previously stored electric field configuration data files step (iii) includes the steps of:

(1) reading from a first previously stored electric field configuration data file where α= a second probe tip geometry descriptor value, a first previously stored electric field value (E_1) and a first permittivity value (ε_{r1}) where ε_{r1} is the permittivity of said thin film having approximately the same second determined thickness and known dielectric permittivity;

(2) reading from a second previously stored electric field configuration data file where α= a second probe tip geometry descriptor value, a second previously stored electric field value (E_2) and a second permittivity value (ε_{r2}) where ε_{r2} is the permittivity of said thin film having approximately the same second determined thickness and known dielectric permittivity;

(3) calculating a point on the second test sample calibration curve by solving the equation

$$\frac{\Delta f}{f} \approx \frac{\epsilon_0}{4W} \int_{V_s} \left(\epsilon_{r2} - \epsilon_{r1} \right) \vec{E}_1 \bullet \vec{E}_2 \, dV \text{ ;and}$$

(4) repeating steps (1) through (3) until a predetermined number of points on the second test sample calibration curve have been generated.

19. An apparatus for displaying dielectric properties comprising:

(a) a near-field scanning microwave microscope having an open-ended coaxial probe with a sharp, protruding center conductor;

(b) a coaxial transmission line resonator that has a resonant frequency;

(c) a microwave source coupled to said coaxial transmission line resonator through a capacitive coupler for generating said voltage;

(d) a spring-loaded cantilever for supporting said sample in contact with said sharp protruding center conductor;

(e) a bias tee coupled to said coaxial transmission line resonator for applying a local electric field to said sample in contact with said sharp protruding center conductor;

(f) a first motor controller for manipulating said sample in contact with said sharp protruding center conductor in a first direction;

(g) a second motor controller for manipulating said sample in contact with said sharp protruding center conductor in a second direction;

(h) a third motor controller for manipulating said sample in contact with said sharp protruding center conductor in a third direction;

(i) a coupler joined to said microwave source and said coaxial transmission line resonator;

(j) a detector for converting the microwave signal from said coupler into an output signal;

(k) a feedback circuit receives the output signal from said

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detector and measures a shift change in resonance frequency, wherein said feedback circuit keeps said microwave source locked onto a predetermined resonant frequency;

(l) a processor for determining between at least one parameter related to a change in said resonant frequency and a known dielectric property value of a sample responsible for said change; wherein the processor is further able to receive from said feedback circuit said value for at least one parameter related to a change in said resonant frequency due to an unknown dielectric property of said sample and determine the value of said unknown dielectric property; and

(m) a display device for imaging the value of said unknown dielectric property once said value is determined by said processor.

20. A system for quantitatively modeling and imaging of dielectric properties, comprising:

(a) a memory device that stores

(i) files of electric field values, ε_r, and α over a predetermined range of ε_r and α, where ε_r is a dielectric permittivity value and α is representative of said probe tip geometry descriptor;

(ii) calibration sample resonant frequency shift values;

(iii) test sample resonant frequency shift values;

(b) a model calibration curve generator that generates two model calibration curves using the stored files in said memory;

(c) a probe calibration curve generator that generates a probe calibration curve using said generated model calibration curves and said calibration sample frequency shift values.

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(d) a test sample calibration curve generator that generates a test samplė calibration curve using additional model calibration curves and additional calibration sample frequency shift values;

21. A spring-loaded sample holder comprising:
   (a) a sample support having an angled end and a planar surface for supporting a sample;
   (b) a first bracing device in contact with the angled end of said sample support so as to create a pivot point;
   (c) a spring mounted to the sample support; and
   (d) a second bracing device in contact with said spring for holding the spring in place.

22. The method of claim 21, wherein a probe is held fixed and in contact with the sample.

23. The method of claim 22, wherein the sample holder and sample are scanned horizontally.

24. The method of claim 23, wherein a sensor measures the vertical displacement of the sample holder, such that this displacement is a function of the topography of the sample.

25. An apparatus for imaging a sample using a near-field scanning microwave microscope, comprising:

a bias tee in a coaxial transmission line resonator for applying a low-frequency bias voltage to a microscope probe tip and wherein the low-frequency bias voltage is independent of a

microwave signal, whereby a local electric field can be applied to a sample to allow for nonlinearity and tunability measuring.

26. A method for non-contact imaging of dielectric permittivity using a near-field scanning microwave microscope having a resonator with a probe tip comprising the steps of:

(a) calibrating the near-field scanning microwave microscope using at least three dielectric samples with known dielectric properties;

(b) generating calibration curves;

(c) scanning a test sample with the probe at a predetermined scanning height and generating at least one test sample frequency shift value at said predetermined scanning height; and

(d) determining the dielectric permittivity of the test sample based on the generated test sample resonant frequency shift value and the generated calibration curves.

27. The method of claim 26, wherein said calibrating step (a) includes the steps of:

(i) selecting a resonant frequency of the near-field scanning microwave microscope;

(ii) placing one of said at least three calibration samples beneath the probe;

(iii) positioning the probe at a first predetermined height;

(iv) measuring a resonant frequency at said first predetermined height;

(v) moving the probe to a second predetermined height;

(vi) measuring the resonant frequency at said second predetermined height;

(vii) calculating the difference between said resonant frequency at said first predetermined height and said resonant frequency at said second predetermined height;

(viii) storing in memory said calculated difference as a calibration sample resonant frequency shift value;

(ix) repeating steps (ii) through (viii) for each of said at least two calibration samples.

28. The method of claim 26, wherein said generating calibration curves step (b) includes the step of plotting said calibration frequency shift values as a function of dielectric constant (ε_r) and frequency shift.

29. The method of claim 26, wherein said scanning a test sample step (c) includes the steps of:

(i) selecting a resonant frequency of the near-field scanning microwave microscope;

(ii) placing said test sample beneath the probe;

(iii) positioning the probe at a first predetermined height;

(iv) measuring a resonant frequency at said first predetermined height;

(v) moving the probe to a second predetermined height;

(vi) measuring the resonant frequency at said second predetermined height;

(vii) calculating the difference between said resonant frequency at said first predetermined height and said resonant frequency at said second predetermined height;

(viii) storing in memory said calculated difference as a test sample resonant frequency shift value.